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STUDY TO DETERMINE THE FEASIBILITY OF ASBESTOS CEMENT SHEETS AS CLADDING FOR CONCRETE OFFSHORE STRUCTURES

FINAL REPORT

BY

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EXECUTIVE SUMMARY

The purpose of the study was to determine the feasibility of using asbestos cement sheets as cladding against ice action in concrete offshore structures.

Physical properties and cost factors were compared for asbestos cement, steel sheets, steel and Teflon, and high strength concrete. The comparison shows that asbestos cement is not well suited to the proposed use.

A library search produced only one relevant research paper. Asbestos cement had been tested in seawater (but not in a cold climate) and in the laboratory to examine its properties for use as sheet piling in a marine environment. The results for normal and for autoclaved asbestos cement were not encouraging. Extracts from the report are included.

The information available strongly suggests that asbestos cement is not well suited to the proposed use on offshore structures. To show this conclusively, it is recommended that tests on asbestos cement in cold seawater be conducted, and the results compared to those for high strength concrete and for steel sheets. These materials are considered to be more appropriate for providing protection to offshore structures.

STUDY TO DETERMINE THE FEASIBILITY OF ASBESTOS CEMENT SHEETS AS CLADDING FOR CONCRETE OFFSHORE STRUCTURES

1. INTRODUCTION

The purpose of the assignment was to conduct an initial feasibility study concerning the possible use of asbestos cement sheets as protective cladding to exposed faces of concrete (gravity based) offshore production platforms exposed to ice impact. A preliminary examination of the advantages and disadvantages of asbestos cement sheet cladding was prepared. No field trials, laboratory tests or other physical testing was carried out.

The report addresses the use of asbestos cement cladding under the following general topics:

- general engineering properties and practicability
- literature search
- alternatives: comparison with other materials (steel sheets, teflon sheets, and concrete without cladding).
- cost considerations.

2. DISCUSSION ON ASBESTOS CEMENT

2.1 Engineering Properties and Practicability

General characteristics are summarized as follows for asbestos cement sheets:

- the material is resistant to abrasion (asbestos fibres wear well).
- mechanical properties generally greater than ordinary concrete although laminar structure is anisotropic (properties vary according to direction considered) and the proportion of each ingredient can be modified to vary physical properties.
- not susceptible to rust, tuberculation, blistering, scaling, resistant to moisture, vermin, decomposition, heat, ultra-violet rays, electrolysis, galvanic currents, alkalis and water that is slightly or moderatley agressive.
- can be subjected to freeze-thaw cycles with no risk of surface scaling or disintegration.
- physical properties not altered by temperature, therefore stable in cold weather.
- can be exposed continuously in seawater if properly treated (e.g. autoclaved at 10 atmospheres at 180°C for about 12 hours).

- material is brittle, therefore holes for fastenings should be pre-drilled.
- many asbestos products are not recommended for weathering surfaces and high humidity applications.

Properties of asbestos cement, concrete and sea ice are provided on the following pages.

Manufacturers, distributors and specialists in the asbestos cement industry were contacted to obtain relevant physical parameters and constraints on available asbestos cement sheeting and fastening alternatives.

Canflex (Turners Building Products Ltd.) advised that asbestos cement sheets are available in general thicknesses of 3 mm to 12 mm and thicker on request. The sheets may also be fabricated as curved sheets to conform to specific structure profiles.

Guilfords recommended that fastenings be of the screw type (pre-drilled as the asbestos board is brittle) and that the thicker sheets are generally too heavy for fastening with an adhesive.

Fastenings recommended by the Atlas Asbestos Co. are a variety of screw type fastenings installed in pre-drilled holes. The use of adhesives

COMPARATIVE ENGINEERING PROPERTIES

	Concrete	Asbestos Cement
Compressive Strength (MPa)	60 - 80	59 - 86
Tensile Strength (MPa)	3 - 5	12 - 15
Modulus of Rupture (MPa)	6 - 8	21 - 35
Modulus of Elasticity (GPa.)	30 - 35	12 - 14
Shrinkage (wet to dry) (%)	0.04	0.1
Water Absorption (% dry mass)	3 - 6	22 - 28
Mass Density (Kg/m^3)	2350 - 2450	1520 - 1680
Thermal Expansion Coefficient	1.1×10^{-5} m/m°C	1.0×1^{-5} m/m°C to 9.0×10^{-6} m/m°C

It is noted that water absorption of asbestos cement is high, and this would adversely affect performance in a marine environment.

COMPARATIVE ENGINEERING PROPERTIES

Sea Ice

Compressive strength	2750 to 4150 KPa
Tensile strength	700 to 1400 KPa
Modulus of rupture	1400 KPa
Modulus of elasticity	9650 MPa
Poisson's ratio	0.35
Mass Density Specific gravity	0.86 to 0.92 (average values)
Coefficient of thermal expansion	0.000028 (avg. between -29° & 0°C)
Adhesion	200 to 700 MPa
Volumetric expansion	9% (on freezing) maximum pressure exerted 200 MPa
Coefficient of friction	0.15 metal to sea ice 0.01 "wet" ice

would also not be recommended because of relative differential movement between concrete and asbestos-cement cladding.

Press Offshore and Norwegian Contractors, specialists in the construction of offshore platforms, could offer no information pertaining to asbestos-cement cladding. There appears to be no use of the material on concrete structures in the North Sea, in the type of application considered in this study.

Fastenings

Water that is trapped in pockets or crevices will expand on the order of 9% in volume during the solidification (freezing) process. This would require that any exterior cladding above the mean water level be sealed or bonded to the concrete surface (eg. with adhesive), to prevent the intrusion of water.

Ice accretion due to rain and freezing spray may be in the order of 0.3 to 0.6 m or more in thickness. Ice is slightly less dense than water with a mean unit weight of about 900 kg/m^3 and can considerably increase vertical dead loads acting on fasteners.

Impact

Higher sea ice compressive strengths generally correspond to lower rates of load application. Very slow moving ice may exert the highest moving forces. For smaller floes and icebergs moving at measured velocities, the force exerted could be calculated by energy methods if a mass, velocity and coefficient of restitution between ice and structure were assumed. Generally, impact loads in the order of 1000 to 1200 KPa of contact area have been suggested for structures located in areas subject to drifting ice. Floating camels or other protective devices are typically recommended to minimize impact damage.

A relatively thin cladding would do little to distribute compressive forces from ice impact and due to the brittle nature of asbestos-cement sheeting, any imperfections in the interface between the concrete surface and cladding, resulting in uneven support, may lead to fracture and subsequent progressive deterioration of the cladding.

Abrasion

Concrete is especially susceptible to abrasion and spalling by ice action. An impervious, low-friction cladding is typically suggested as a possible protective measure. Asbestos-cement cladding is not considered as either impervious or as a low-friction surface although asbestos fibre is abrasion resistant. For these reasons alone, the material does not lend itself well to the proposed use.

2.2 Literature Search

A literature search was carried out using the following key words: asbestos, cement, sheets, cladding, offshore platforms, ice, abrasion, marine and properties, in various combinations.

The only relevant article found in the search deals with the deterioration of asbestos cement sheet material in the marine environment. Extractions from this report are provided, as follows:

Deterioration of Asbestos Cement Sheet Material in the Marine Environment (Working Paper)

Machemehl J.; Watson, L.; Barnes, B.

North Carolina State University at Raleigh. Department of Marine Science and Engineering.

Sponsor: National Oceanic and Atmospheric Administration, Rockville, MD. Office of Sea Grant.

Report No.: UNC/SG/WP-78/1; 78/6; NOAA-79042702

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Languages: English

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ABSTRACT

Tests were conducted on asbestos cement sheet piling to determine the causes of corrosion to the material along the North Carolina coast. New sheets of asbestos cement were obtained from which 78 specimens were fabricated. A wetting/drying apparatus was used to simulate tidal conditions. Three months of wetting/drying were carried out with both fresh water and seawater. Asbestos cement samples were removed at the end of each month and tested for tensile strength. Selected samples were then examined with the aid of the X-ray diffractometer and scanning electron microscope for determination of material composition. A study of an asbestos cement bulkhead from the field was also conducted. Samples were tested for tensile strength, then analyzed with the diffractometer and scanning electron microscope.

DISCUSSION OF RESULTS

Cement is susceptible to deterioration by many corrosive agents, including carbonic acid, sulphates, and leaching which have been investigated. Evidences of these types of corrosion have occurred in both the field and laboratory specimens. The means of deterioration progression, however, appear to be different between the field and the laboratory.

The Processes of Asbestos Cement Deterioration in the Field

The results of the various tests on the field specimens indicated that the material originating from below the water line had little structural integrity remaining. The relatively high porosity of the material allowed for extreme percolation. Also, with the thickness of the asbestos cement sheet being only 0.95 cm (0.375 in.) this percolation was allowed to flow through the entire cross-section in probably a very short time. Since the material was not autoclaved, there was a possibility of some free $Ca(OH)_2$ existing in the asbestos cement. Barring complete carbonation through atmospheric CO_2 before placement in the canal, this $Ca(OH)_2$ could easily have been leached out of the bulkhead, taking away a portion of the structure's mass.

Based upon the ACI limits to avoid sulphate aggressivity, corrosion of the asbestos cement by sulphate salts can be disregarded due to the low sulphate concentration of the canal water. X-ray diffraction patterns failed to indicate any peaks which can be attributed to the common sulphate salts (i.e. ettringite and gypsum) to substantiate these results. Also, the lack of cracks either along the surface of the material or visible throught the SEM gives further proof to the absence of expansion, which is common to sulphate attack.

Carbonic acid attack is considered the principal cause of deterioration of the asbestos cement bulkhead from the field. Analysis of the canal water revealed a high enough free CO_2 level existing in the presence of acidic water to attack the cement by the process mentioned by Biczok (1967). A look at the x-ray diffraction patterns indicated that $Ca(OH)_2$ was absent, at least in significant quantity. By the presence of extensive amounts of calcite, it can be concluded that the free $Ca(OH)_2$, present as a hydration product, reacted with atmospheric CO_2 to form $CaCO_3$. Since $CaCO_3$ is most stable in the form of calcite, the absence of the polymorphs vaterite and aragonite suggests that the $CaCO_3$ had been formed for quite some time. The change in the intensity ratio of calcite with respect to asbestos above and below the water line indicates that the $CaCO_3$ is being dissolved through some process. Calcite itself is highly insoluble even in seawater, but in the presence of aggressive CO_2 it is capable of dissolving in the form of the bicartonate, $Ca(HCO_3)_2$, which is so soluble in saline water that it will likely dissolve directly upon formation in seawater. The SEM confirmed the fibrous appearance of the specimens from below the water surface due to loss of calcite, which, according to the diffraction patterns, had become the only constituent of the material.

The Processes of Asbestos Cement Deterioration in the Laboratory

The results of the tests conducted on the laboratory specimens did not present as clear cut a solution as those for the field specimens. Although the seawater-tested specimens exhibited tensile strengths on the same order as those tested in fresh water, the presence of hairline fractures along the edge of the samples exposed to seawater for greater than one month was plainly an indication of some form of aggressive attack on the cement. Also, the increase in the amount of calcium in the seawater due to wetting/drying of the cement pointed to a reaction of the insoluble calcium compounds to form a more soluble compound.

Carbonation is ruled out in this case, as the water is an alkaline solution. Also, the x-ray diffraction patterns showed no significant change in the intensity of $CaCO_3$ with time other than the transition from vaterite to calcite.

Sulphate attack of the ettringite form is not evident by either the diffraction patterns or observations with the SEM. Ettringite's largest diffraction peak occurs at 9°, 2θ, and it is clear from Figure 13 that no identifiable peak is present at this angle in any of the seawater-tested specimens. With the SEM an examination at high magnification of the hairline fractures found in samples 6-O and 5-J was possible. However, neither the needle-like structure of ettringite nor expansive crystal formation inside the cracks were observed.

The lack of expansive crystals also ruled out the classical form of gypsum attack on the cement. Yet, gypsum was clearly evident in the seawater samples, while none was exhibited in the control material. Historically, it has been assumed that the presence of $Ca(OH)_2$ is essential to the formation of gypsum in cement. With the asbestos cement tested in the laboratory having been cured in an autoclave, there should have been no $Ca(OH)_2$ available to react with the sulphates through this process. X-ray diffraction patterns further substantiated this by a lack of $Ca(OH)_2$ in the control samples. Therefore, gypsum must have been formed through a reaction which is unknown to the author.

Comparison Between Field and Laboratory Results

The data from the field and laboratory tests leads to different conclusions. This can be attributed in part to the difference in the SO_4 and CO_2 content the pH of the seawater used in the laboratory test as compared to those characteristics of the canal water. Other variations in the results can be attributed to idealized conditions in the laboratory, where free CO_2 could not be formed as in the field, and the use of an autoclaved product in the laboratory, when the field material had been normally cured. One factor involving the lack of a definite corrosion pattern through the results of the laboratory test was the short length of time of the testing. A longer test might have led to a better understanding of the destructive processes which caused the formation of hair-line cracks in the asbestos cement specimens.

SUMMARY AND CONCLUSIONS

Summary

Tests were conducted to determine the performance of asbestos cement used in bulkhead/retaining structures along hte coastline of North Carolina. The study included a three-month laboratory wetting/drying test, an examination of a deteriorated asbestos cement bulkhead from the field, and analysis of material tensile strength, water quality, and absorptive properties of the material, and tests for material composition through x-ray diffration and scanning electron microscopy.

Conclusions

1. The asbestos cement bulkhead under investigation from the field was severely deteriorated through the reaction of aggressive CO_2 with $CaCO_3$ in the material. The $Ca(HCO_3)_2$ which was formed was leached out of the structure in solution, thus causing a drop in material density and increase in porosity.

2. As reported in the literature and substantiated by the study, asbestos cement bulkheads are vulnerable to carbonic acid attack in canals and estuaries where biological decay produces an excess of dissolved CO_2 and the water's pH is less than 7.

3. Autoclaved asbestos cement as opposed to normally cured* asbestos cement may be helpful in delaying extensive deterioration due to carbonic acid. It contains a high amount of silica which is non-reactive at normal temperatures.

4. Autoclaved asbestos cement is subject to corrosion in seawater. The cause of this corrosion is debatable, but it is likely that the presence of a sulphate concentration along with the wetting/drying process invoked by tidal action plays a major role in the mechanism of deterioration.

RECOMMENDATIONS FOR FUTURE CONSIDERATION

1. A prolonged wetting/drying study in the laboratory to simulate up to 5 years in the field should be conducted for a better understanding of the mechanisms of corrosion of autoclaved asbestos cement.

2. An investigation into possible coatings for asbestos cement products needs to be carried out.

3. A laboratory study to confirm the limits of CO_2 attack should be accomplished. In addition, a more thorough analysis of the agressive pH and CO_2 levels in the field should be accomplished.

4. A freeze/thaw study should be made to determine the durability of asbestos cement in cold climates.

* our correction

2.3 Alternative Materials:

Teflon, steel and concrete are considered as alternative materials for the proposed use.

Teflon:

In general, Teflon is characterized by stability between -200°C to +260°C, low coefficient of friction, nonsticking properties, excellent abrasion resistance, good electrical properties, excellent chemical resistance to nearly all chemicals except molten alkali metals and fluorine at high temperatures, low moisture and vapor permeability, and resistance to ultraviolet and nuclear radiation.

Properties of Teflon may be changed through modification of the material, using fillers such as glass fibres, asbestos, and metallic powders. These fillers generally improve dimensionl stability.

Teflon is generally used in thin laminations, etched on one face to allow bonding to a rigid backing (such as steel plate) as the Teflon is relatively pliable and too expensive to justify the use of thick laminations.

Fastening of thick sheets may be by counter-sunk screws. In thin laminations, fastening would be by bonding to a steel backing plate. This

plate would then be anchored into the concrete with typical anchors common to concrete construction. The use of Teflon would provide a flexible, resilient and low-friction cladding. The coefficients of thermal expansion of steel and concrete are compatible and a thin lamination of pliable Teflon bonded to steel would not lead to a fastening problem.

A significantly thick backing plate would be required to distribute localized compressive ice loadings. The Teflon laminate may not significantly improve the performance of a plain steel plate as the coefficient of friction for ice on steel is very low and a thicker steel cladding would better distribute impact stresses.

Steel:

Steel sheet cladding may be provided in the form of regular grade carbon steel sheeting or a stainless steel grade.

Both types of sheeting will provide relatively low-friction surfaces to ice and can mitigate localized impact stresses if provided in sufficient thickness.

As noted previously, anchorage of steel cladding is compatible with concrete structures.

Concrete

Protection against ice impact and abrasion damage can be provided in the form of an additional thickness of very high strength (greater than 70 MPa) concrete. The use of additional thickness should, however, be used with caution as it can induce cracking, which would be very undesirable. In this application use could be made of high strength fibre reinforced concrete on the outside skin (50 mm).

This form of protection lends itself to current slipforming construction practices and has an economic advantage as there would be no separate installation phase and associated costs. The extra cladding thickness would be an integral part of the structure.

Corrosion Considerations

Asbestos cement sheeting: fastening may have to include a combination of recessed stainless fastenings to prevent corrosion and a bonded interface with concrete to prevent ice formation at the interface and to provide a uniform bearing surface. Asbestos cement would appear to be subject to deterioration in a marine environment unless specially treated or cured.

Teflon sheeting: recessed stainless fasteners combined with bonding to concrete would prevent corrosion of fasteners and lifting due to ice formation at the interface. Teflon is not affected by immersion in a marine environment.

Teflon bonded to steel: the steel backing plate and anchors would have to be bonded to the concrete or coated on the inner face to prevent corrosion.

Carbon Steel: affected primarily by corrosion in the tidal zone which may be in the order of 0.25 mm/yr on each face exposed. Therefore bonding of the back face would limit corrosion of steel to one face. A minimum plate thickness of 12 mm is recommended to give a reasonable minimum thickness after corrosion.

Stainless Steel: not as susceptible to corrosion although special attention to the anchorage (eg. galvanizing or stainless fittings) may be required.

High Strenght Concrete and Increased Thickness	not corrosion susceptible if proper concrete mix used. Damaged areas can be patched. Not susceptible to ice formation at the interface which would lift a typical laminate off.

Cost Considerations

Asbestos cement sheets (prices from Guilford's):

-- typically available in sheets 1200 mm x 2400 mm in various thicknesses at approximately $1.60/kg.

Steel Cladding (prices from Drummond McCall)

-- typically available in sheets 1200 mm x 2400 mm in various thicknesses.
-- regular carbon grade steel at approximately $0.82/kg.
-- stainless steel, Type 304, at approximately $4.08/kg.

Teflon (prices from Cadillac Plastics)

-- typically available in sheets 1200 mm x 1200 mm in various thicknesses at approximately $33.07/kg.

-- an additional cost of $30.00/m^2 applies for etching to allow bonding on one side.

Concrete (prices based on typical slipform construction)

-- additional slipformed wall thickness, reinforced, approximately $0.11/kg.

Comparative costs are provided as follows, based on practical cladding thicknesses:

1)	Asbestos cement cladding	12 mm thick	=	$ 35/m^2
2)	Carbon steel cladding	12 mm thick	=	$ 100/m^2
3)	Stainless steel cladding	12 mm thick	=	$ 500/m^2
4)	Teflon	12 mm thick	=	$1,000/m^2
5)	Teflon on steel backing	5 mm + 12 mm thick	=	$ 950/m^2
6)	Concrete cladding	80 mm thick	=	$ 20/m^2

Compared to asbestos-cement or concrete alternatives, thinner sheets of Teflon and/or steel would provide equivalent protection to a concrete surface from ice impact and abrasion. Therefore the cost differential would be reduced.

Generally a thin low-friction surface lamination is adequate to mitigate abrasion damage. To distribute stresses from localized ice impact a thick cladding would be preferred.

Based on the representative prices presented, one can see that increased concrete thickness of about 140 mm can be provided for the equivalent price of 12 mm thick asbestos cement cladding. Generally, concrete cover in the order of 75 mm concrete thickness is provided for marine structures subject to a seawater and ice abrasion/impact environment.

The alternatives of steel, and Teflon and steel combined, would generally be considered uneconomical, as a minimum accepted thickness of 12 mm for a marine environment costs substantially more than a reasonable increase in concrete thickness.

3. SUMMARY AND CONCLUSIONS

Based on the considerations of practicability, fastening, lifetime and relative cost considerations, it would appear that an asbestos cement sheet cladding would not be preferred to the alternative of high strength concrete and some increased concrete thickness, to mitigate ice impact deterioration of concrete offshore platforms.

The alternatives of Teflon or steel would be considered uneconomical when compared to additonal concrete cover to protect against ice impact.

There is little information available on the performance of asbestos cement in the marine environment, and no information was found on its performance in seawater in cold environments.

From the information available, asbestos cement appears to be very poorly suited to the proposed purpose, compared to high strength concrete or conventional steel plates. It is recommended that in order to resolve the matter more conclusively, that tests be conducted on regular and autoclaved asbestos cement. Testing should include immersion in sea water, application of freeze-thaw cycles and measurement of resultant physical properties including absorption, compressive strength, tensile strength and modulus of rupture. Impact testing would also be advantageous. The results should be compared with properties of high strength concrete and with steel, which are considered to be more appropriate cladding or protective materials.